Robotic Systems

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Document #: N0001499WX30008

LONG-TERM GOALS

Teleoperated mobile platforms and robotic manipulators that are currently being introduced into the field are expected to assume a larger role in the access and neutralization of area denial and explosive devices. This role includes the examination, identification, and disposal of ordnance. Current commercial and developmental arms either are too expensive for use in explosive ordnance disposal (EOD) or do not have the flexibility and strength-to-weight ratio necessary for render-safe procedures (RSPs). In the effort reported here, technologies leading to serpentine manipulators and legged locomotors that incorporate muscle-like electroactive polymer (EAP) actuators were explored. Manipulators and robotic platforms using these technologies would provide the operator, who is out of harm's way, with high dexterity or mobility, which makes them valuable for the complex and obstructed environments that are common in the field.

OBJECTIVES

The key to development of the manipulator is a new actuation technology, an EAP artificial muscle that has been developed at SRI. Muscle-like actuators based on this technology have the combination of high energy-output-to-weight ratio, large stroke capability, good speed of response, and high efficiency unavailable in other actuation technologies. The use of such actuators will allow for the development of an extremely lightweight and slender manipulator with a sufficient number of degrees of freedom to negotiate around obstacles. The objective is to develop and demonstrate this technology with a highly dexterous serpentine manipulator that employs "follow the leader" control methodology for EOD access missions. A secondary objective is to demonstrate the application of this technology to legged locomotion of a small UXO-gathering platform.

APPROACH

A breakthrough is needed to reduce the cost for a high-strength, high-dexterity, and low-cost manipulator. A promising technical approach to this problem is the use of EAPs as actuators. Thin snake-like manipulators with a high number of degrees of freedom that would be capable of positioning an end-effector in a highly cluttered environment are not available. The main obstacle to their development has been the lack of lightweight and compact actuators capable of producing the needed forces (or torque), displacements, and speed of response. Many multi-articulated arm designs have placed the actuators on the manipulator base to avoid the issue of actuator size and mass.

The basic building-block of SRI's EAP technology is a rubbery polymer that is sandwiched between two compliant electrodes. When a voltage difference between the two electrodes is applied, the resulting electrostatic force compresses the thickness and expands the area of the polymer film. This deformation of the film is used for actuation.

The energy output of electroactive polymer muscle can be very large. Silicone-rubber, a material that has proven to produce rugged reliable actuators, has produced strains in excess of 100%, pressures greater than 100 psi and specific energy densities exceeding that of all known field actuated materials (such as piezoelectrics and magnetostrictive materials) in response to an applied voltage. These values are much larger than those suggested by the breakdown voltages quoted in industrial literature. The key to achieving higher breakdown voltages is to use high-quality thin films, and eliminate any remaining electrical defects prior to operation. Key technical challenge in this project are: 1) scaling up the extremely high performance of micro-size samples; and 2) the developing lightweight actuators that efficiently convert the high energy of deformation of the polymer into mechanical work.

WORK COMPLETED

Work during FY 2000 focused on developing linear muscle-like actuators with improved electroactive polymers and designs. These actuators were applied to demonstration devices, joints of a serpentine manipulator, and the leg actuator of a six-legged walking robot.

The improved polymers were based on the use of a newly discovered acrylic polymer with exceptional strain response and high energy output. This polymer is available from the 3M Company (VHB series)[1] in rolls with varying thicknesses. SRI used rolls with 1.0 mm and 0.5 mm initial thickness.

Large strains in a single direction are desirable for muscle-like actuators. While scale-up actuators have not achieved large amounts of strain in a single direction, greater performance than other actuator designs has been demonstrated. Since the strain in the direction along the width of the line is almost zero, one might attach relatively rigid spars along the length of the line without affecting the strain response. If these spars are then attached to mechanical connectors that can exert a suitable load in the transverse direction, then the film could be removed from a rigid frame without compromising the strain performance. Such a construction is the basis of our improved musclelike linear actuators. An example of such a linear actuator is shown in Figure 1.

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[1]All product or company names mentioned in this document are the trademarks of their respective holders.

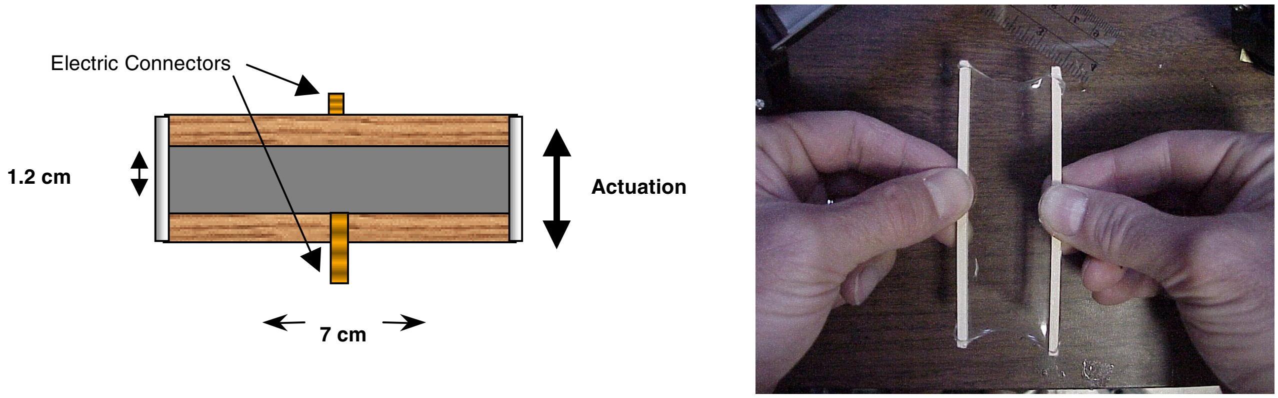

Figure 1. Linear Musclelike Actuator Using Directional Compliance

In addition to their work with the acrylic polymer, SRI continued to improve their linear actuators based on prestrained silicone. The primary focus of this work was to modify the design for better stacking of the actuators in parallel for achieving greater force. SRI therefore returned to the two-layer design. In this design, two electroded polymer layers are laminated together by glue around the edges. This sealing of the electrodes prevents arcing when the actuators are in close proximity. Further, if the high voltage is applied only to the sealed electrodes, the electrodes are less likely to arc to other actuators or supporting structures. SRI demonstrated two such actuators operating in parallel. After several weeks, the actuators showed no evidence of adverse interaction.

A variation of this linear actuator is the "stretched film" actuator. Here, the polymer film is stretched on a rigid frame and mechanical connections are made directly to connectors on the film itself. An example of this type of actuator is shown in Figure 2. The primary advantage of the stretched film actuator is its ease of manufacture and durability. Also, the frame makes is unnecessary to handle a freestanding thin polymer film. The real advantage is that the inactive or opposing portion of the film relaxes (due to creep) at the same rate as the active portion (assuming that the actuator is not loaded), so the effects of creep are canceled or balanced to a large extent.

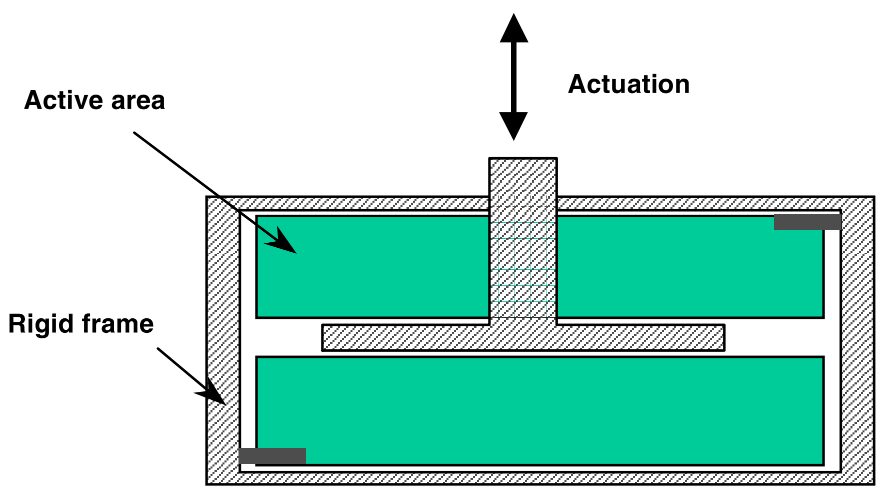

Figure 2. Linear Stretched-Film Actuator
Two active areas are shown for "push-pull" operation.

The serpentine joint is similar to that reported previously in FY 1999 for the “bow-tie” linear actuators. However, these linear actuators have a very high aspect ratio, so they cannot be used for bending in two axes in a single joint. SRI built their serpentine manipulator from a series of these joints in which every other joint is rotated 90° with respect to the initial joint. Any two adjoining joints form a spherical joint that can move about an arbitrary axis. SRI fabricated several such modular joints. These proof-of-concept joints were made from relatively heavy plastic, but in a final design much of the mass of the joint could be eliminated by the use of lighter materials and a design that more effectively incorporates the rigid end pieces of the linear actuators into the joint structure. Thus, these end pieces served a dual purpose: actuator connection and manipulator structure.

RESULTS

In this project, now ending its third and final year, SRI undertook a wide range of research aimed at exploiting electroactive polymers for NAVEODTECHDIV’s needs. This section summarizes these directions and identifies those that were successful, those that were not, and those that are believed to have unrealized potential.

The primary focus at the outset of this project, after discussions with NAVEODTECHDIV, was to develop a low-cost serpentine manipulator 1–2 m long, using electroactive polymers. To this end SRI explored many actuator and manipulator joint designs as well as different polymer materials. At the conclusion of this project SRI claimed only partial success. SRI developed linear actuator elements and manipulator joint designs that could, in principle, be incorporated into a low-cost serpentine manipulator. However, these designs are limited to an extremely small payload and extremely lightweight structural elements joints included. Because the primary function of the manipulator would be to carry a video camera, this function is fundamental. In practice such a manipulator will be fragile or costly. One attractive solution to this problem is to make the manipulator structure entirely from electroactive polymer. SRI demonstrated small-scale implementations of this approach, including bending “quadramorph” rolls (four rolled actuators bound together) and bimorph actuators. However, SRI was unable to extract from the individual actuator elements the level of performance that would enable them to demonstrate larger manipulators. Continuing development of the actuator materials and designs may enable the realization of such designs in the future.

The demonstration of the application of EAP actuators to legged motion was successful. The SRI linear actuator was able to reproduce the force vs. stroke behavior of natural skeletal muscle. These actuators were incorporated into demonstration devices that showed their efficacy for robotic applications. These demonstration devices included several actuator designs, polymer materials leg geometries, and robot designs. The demonstration devices were simple in the sense that the actuators drove only a single degree of freedom. However, they demonstrated that the basic force and stroke requirements could be met with actuators that could be integrated into a robotic system. These biologically inspired robots offer the promise of increased mobility, robustness, lightweight systems, and low cost. This work is feeding directly into a newer follow-on project (with NAVEODTECHDIV) whose goal is to build an operational six-legged insectlike robot. The robot will attempt to make use of the passive and active musclelike capabilities of direct-drive polymer actuators in order to realize robust locomotion.

All of the musclelike actuators that SRI demonstrated are modular and should scale well to smaller sizes. This ability will allow the future realization of insect-size robots with good sensory capabilities. These small robots will be low cost and will provide faster, more effective, and less energy-intensive coverage of terrain that might contain UXOs.

IMPACT/APPLICATIONS

There is a specialized need for an arm that can move precisely inside an object without toughing any surfaces. Arm control must be precise, slow, and deliberate. The inadvertent bumping of the arm into bomb components, electronics, or structure may have disastrous results. The EOD technician must be able to spatially determine the exact location of the arm during a procedure. The arm must operate at a slow speed. A computer will track where the arm has been and, therefore, where it may not deviate when withdrawn. An artificial muscle, electroactive material construction, would have a vast array of applications that would serve as prime movers for: “sloth” type serpentine arms; inexpensive bomb disablement and UXO retrieval robots; and artificial prostheses.

TRANSITIONS

This technology will transition to both conventional EOD Joint Service programs and for specialized mission groups that support the Army’s 52nd Ordnance Group. The technology for polymer muscles will be transitioned to ongoing EOD programs to enhance actuator performance and reduce cost.

RELATED PROJECTS

In FY99 SRI began a separate project funded by ONR to develop a small-legged UXO-handling robot using their artificial muscle actuators. This work will build directly on their development of the linear artificial muscle actuators and leg demonstrations performed under the current contract.

SRI also has a project with DARPA, now in the second of a three year effort, to develop a biomorphic flapping-wing micro air vehicle. SRI is using EAP muscles to actuate flapping motion.

Since 1992 SRI has been working under a contract that is funded by the Japanese government, with the Micro Machine Center of Japan, to develop small actuators for small robots and micro machine applications. This work has focused on the development of EAP materials and small actuator devices.

REFERENCES

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